PHYSICAL, MECHANICAL AND THERMAL CONDUCTIVITY OF CONCRETE CONTAINING GRANULATED RECYCLED PET BOTTLE

ZAINORA BINTI MISRI

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To my beloved family, lecturers and friends
Thank you for all your support and encouragement
May ALLAH protect you and bless you more than enough
My love to you all will always remain

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ABSTRACT

Concrete is the most extensively used material in the construction industry. Its high demand has threatened the environment and led to the depletion of natural resources such as sand, which is the basic material of concrete. Many strategies have been proposed to overcome these issues, such as reusing waste materials in concrete production. Therefore; the aim of this study is to investigate the effect of granulated recycled polyethylene terephthalate (PET) bottle as sand replacement on physical, mechanical and thermal conductivity of concrete. In this research, the ground PET were sieved passing 5 mm sieve size with 5%, 10% and 15% replacement amount. The total of 120 samples with cube, cylinder, beam and panel size were cast. At fresh stage, slump test was conducted to determine the workability of concrete. As of hardened stage, density, water absorption, compressive strength, split tensile strength, flexural strength, modulus of elasticity and thermal conductivity were tested on samples at 7 and 28 days. The percentage of PET replacement that up to 10% had obtained the target strength of 30 MPa concrete grade, and acceptable value of thermal conductivity which performs same properties of normal concrete. However, the recommended percentage of PET aggregate was up to 5% due to its achievement as highest compressive strength, split tensile strength, flexural strength and modulus of elasticity which the values are 33.9 MPa, 3.20 MPa, 4.3 MPa and 21111 MPa, respectively. Based on the overall physical, mechanical and thermal performance, concrete with 5% PET replacement is appropriate to be used in concrete production. Therefore, PET can be used as an alternative material of the aggregate in producing concrete in a construction industry.

ABSTRAK

Konkrit adalah bahan yang paling banyak digunakan dalam industri pembinaan. Permintaannya yang tinggi telah mengancam alam sekitar serta menyebabkan pengurangan sumber semula jadi seperti pasir, yang merupakan bahan asas konkrit. Pelbagai strategi telah dicadangkan untuk mengatasi masalah-masalah ini seperti mengguna semula bahan-bahan tersisa sebagai bahan gantian di dalam konkrit. Berikutan itu, kajian ini bertujuan untuk mengkaji kesan polyethylene terephthalate (PET) sebagai pengganti pasir terhadap prestasi fizikal, mekanikal dan kekonduksian terma konkrit. Dalam kajian ini, PET yang melepasi saiz ayak 5 mm telah digunakan dengan jumlah gantian 5%, 10% dan 15%. Sebanyak 120 biji sampel bersaiz kiub, silinder, prisma dan panel telah disediakan. Pada peringkat konkrit basah, ujian keruntuhan telah dijalankan untuk menentukan kebolehkerjaan konkrit. Manakala ujian ketumpatan, penyerapan air, kekuatan mampatan, kekuatan tegangan berpecah, kekuatan lenturan, modulus keanjalan dan kekonduksian terma telah diuji ke atas sampel yang berumur 7 dan 28 hari. Hasil kajian menunjukkan bahawa penggunaan PET telah mengurangkan sifat fizikal dan mekanikal konkrit. Penggantian PET sebanyak 10% telah mencapai kekuatan sasaran konkrit iaitu 30 MPa, dan nilai kekonduksian terma optimum untuk menghasilkan prestasi yang sama seperti konkrit normal. Namun, penggantian PET yang disyorkan ialah 5% kerana ia mampu mencapai nilai tertinggi dalam kekuatan mampatan, kekuatan tegangan berpecah, kekuatan lentur dan modulus keanjalan dimana masing-masing mempunyai nilai 33.9 MPa, 3.20 MPa, 4.3 MPa dan 21111 MPa. Berdasarkan keseluruhan prestasi fizikal, mekanikal dan juga terma, penggantian PET sebanyak 5% sesuai digunakan dalam pembuatan konkrit. Oleh itu, PET boleh digunakan sebagai bahan alternatif batu baur untuk menghasilkan konkrit dalam industri pembinaan.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Area
Ac	-	Cross-sectional area
ACI	-	American Concrete Institute
ASTM	-	American Society for Testing & Materials
Avg	-	Average
BS	-	British Standard
cm^3	-	Cubic centimeter
d	-	Depth
D	-	Diameter
DMA	-	Dynamic Mechanical Analysis
DOE	-	Department of Environment
E	-	Young's Modulus
E'	-	Storage modulus
E"	-	Loss modulus
et al.	-	And others
F	-	Maximum load
f_c	-	Compressive strength
FKAAS	-	Fakulti Kejuruteraan awam dan alam sekitar
g	-	Gram
g/cm^3	-	Gram per cubic meter

Hz	-	Hertz
k	-	Thermal conductivity coefficient
Kcal	-	Kilo Calorie
kg	-	Kilogram
kg/m^3	-	Kilogram per cubic meter
kN	-	Kilo newton
L	-	Length
M	-	mass
M1	-	Dry Mass
mm	-	Milimeter
mm^2	-	Milimeter square
M^3	-	Meter cube
MOE	-	Modulus of Elasticity
MPa	-	Megapascal
MS	-	Malaysian Standard
N	-	Newton
N/mm^2	-	Newton per millimeter square
OPC	-	Ordinary Portland Cement
PC	-	Plain concrete
PET	-	Polyethylene Terephthalate
PETC	-	Polyethylene Terephthalate Concrete
Q	-	Flow rate
s	-	Second
SAJ	-	Syarikat Air Johor
SEM	-	Scanning Electron Microscope
TC	-	Thermal conductivity
Tg	-	Glass transition temperature

UTHM	-	Universiti Tun Hussein Onn Malaysia
V	-	Volume
W1	-	Oven dry weight
W2	-	Immersed weight
W/mK	-	Watts per meter-Kelvin
W/C	-	Water cement ratio
ΔT	-	temperature gradient
ρ	-	Density
π	-	Pi
%	-	Percent
≤	-	Less-than or Equal to
≥	-	Greater-than or Equal to
°C	-	Degree Celsius
°C/min	-	Degree Celsius per minute
μ	-	micro
μm	-	Micro meter
σ	-	Tensile strength
σy	-	Yield strength
σct	-	Split tensile strength

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CHAPTER 1

INTRODUCTION

1.1 Research background

Malaysia is one of the developing countries which is still depending on the usage of concrete as an essential material in building construction. Concrete is widely used as a primary construction material for various types of structures as compared to other engineering materials, such as wood, steel, and aluminium (Suhendro, 2014). Apart from its low cost and long service life, concrete has been widely known for its structural stability, fire resistance and durability (Nibudey *et al.*, 2013).

The constituent materials in concrete production mainly consist of three essential elements, which are cement (binding material), aggregate and water. Approximately 60 to 80% volume of concrete consists of aggregates which are commonly obtained from natural resources (Rafieiznooz *et al.*, 2016). However, sand plays a vital role as a fine aggregate, and its availability is not universal. It was earlier observed that some types of sand might be inappropriate for construction use due to poor quality, weak in strength and chemical reaction (Gambhir, 2013). This issue causes depletion of natural resources like river sand which is extensively used as an aggregate in the construction industry. Previously, many attempts have been made in order to improve the properties of concrete in terms of workability, strength,

and durability. These properties are most affected by the relative amount of the materials.

On the other hand, the modern lifestyle and industrial development left behind more waste products. However, most of these waste materials are non-disposal and non-biodegradable, which will remain in the environment (Rahmani *et al.*, 2013). Waste disposal problem especially plastic is a very common issue concerning to waste materials. According to Ramadevi *et al.* (2015), the problem of disposing and managing solid waste materials in all countries have become one of the significant environmental issues. Plastic has become an inseparable and integral part of our lives. With the space scarcity for landfilling and due to its increasing cost, waste utilization in concrete construction has become an attractive alternative to minimize the waste.

Recently, a new development in concrete construction has been found by adding granules from Polyethylene Terephthalate (PET) wastes into the concrete. PET is a kind of polyesters made of the ethylene glycol and terephthalic acid, and it plays a vital role in industrial production. PET is one of the most commonly used plastic material in the packaging industry because of its strength, high thermos-stability, excellent water and moisture barrier and less breakable than other materials. These characteristics make PET attract manufacturers around the world. However, the consumption of PET is on an upward trend until now, and this results in waste generation. Therefore, there is a dire need to research reusing plastic waste in concrete production.

However, this study investigated the effect of PET granules as a sand replacement in concrete on physical, mechanical and thermal conductivity performance as a way to produce eco-friendly and sustainable building materials. It makes the concrete more economical and at the same time, there is a solution to the waste disposal issue (Foti, 2013). This study intends to promote sustainable development and increase awareness of the implications of construction projects on the environment. Besides that, it could also contribute new knowledge about the thermal conductivity of concrete containing recycled PET bottles.

1.2 Problem statement

In this study, the issues produced from concrete and PET consumption have brought the idea of the production of PET Concrete. As concrete is highly demanded, it resulted in the depletion of natural resources such as sand. In which, the use of sand involves a significant consumption of its constituents that participate partly in the performance of concrete (Larbi *et al.*, 2015). Despite of its high demands, the needs for improvement of its performance should be emphasized in term of its physical, mechanical or thermal behaviour. Many research previously highlighted on physical performances only. However, interest in thermal performance is still lacking. Thermal performance of concrete need to be improved, as today, global energy issue rises due to extreme weather events such as heatwave. Heats from the environment which transferred into the buildings will cause discomfort to the user since most people spend around 90% of their lives indoors (Shafigh *et al.*, 2018). Hence, thermal conductivity factor should be taken into consideration to study the ability of concrete to transfer or conduct heat.

On the other hand, PET waste is a severe problem for the environment because of its inability to decompose naturally in which led to the disposal problem and environmental hazard. According to Rahmani *et al.* (2013), PET materials are non-disposal and non-biodegradable, which will remain in the environment. The PET waste cannot be disposed of by dumping or burning easily due to uncontrolled fire or soil contamination (Ramadevi *et al.*, 2012).

The utilization of waste PET as fine aggregate replacement in concrete will be giving a good alternative to reduce the use of natural resources and solve the plastics waste problems. Through experimental approached, this study is conducted to evaluate the mechanical properties; compressive strength, tensile strength and flexural strength which enhance the understanding of concrete containing PET as sand replacement. Furthermore, thermal conductivity was conducted in order to understand the effect of PET on the heat transfer process in concrete, which will significantly influences the energy consumption of the buildings.

1.3 Objectives

This study aims to examine the possibility of using granulated recycled PET bottles as sand replacement materials. The details objectives are:

1) To study the physical and mechanical properties of concrete containing granulated recycled PET as sand replacement.
2) To investigate the effect of granulated recycled PET on the thermal conductivity of concrete.

1.4 Scope of work

This study is focused on the possible use of polyethylene terephthalate waste (PET) to substitute partially as sand-replacement (fine aggregate) used in the production of concrete. This research goes through several phases: the field activities, laboratory works, mathematical and statistical analysis. Field activities involve collecting waste of mineral bottles around Universiti Tun Hussein Onn Malaysia (UTHM), with the same brand and size.

The waste PET bottles were ground into irregular size in the range of 0.1 mm to 5 mm using a plastic granulator machine and were used as the fine aggregate at the replacement volume of 0%, 5%, 10%, and 15% in concrete. The concrete specimens with and without plastics are prepared for comparison purposes. All the samples were tested in a laboratory to determine their physical, mechanical and thermal properties after the curing period. Curing is a process that is controlling the rate of moisture loss during cement hydration, not a measure of strength. However, the strength of concrete is affected by the cement hydration process. This study is focused on the effect of PET aggregate in normal strength concrete. Hence, the curing period of 7 and 28 days was appropriate to determine 65% and 99% of specified strength, respectively. According to ACI 318-19, 7days of curing age is used to monitor early strength of concrete while specified compressive strength shall be based on the 28days. The mix proportions for all specimens in this research were designed based on the Department of Environment (DOE) method with target strength of 30 N/mm^2 at 28 days.

1.5 Research significance

As generally known, concrete and PET are progressively high demanded which the consumption of these materials is arguably crucial in the development of life. However, several issues arise due to their global use such as the depletion of natural resources and environmental problems. Concrete incorporated large amounts of natural resources as fine aggregate, for example, sand. In turn, the pricing of the sand increased due to the difficulty to locate adequate sources of sand. It has led to higher construction costs as concrete manufacturers have to raise prices for concrete supply. Meanwhile, the discarded PET bottle turned into an environmental hazard due to its disposal problem. In Malaysia, awareness among individuals about plastic recycling remains weak as there is still a lot of plastic waste in landfills which can be seen obviously. Therefore, the idea of utilizing PET bottle waste as sand replacement has been come in to practice; it could contribute to environmental sustainability by helping the recycling process to be carried out on a large scale. Besides, this study supports the concrete manufacturers to find an alternative way to reduce the production cost, thus making the construction cost affordable to society.

Nowadays, the rapid development of buildings and infrastructure has affected the global energy demand in Malaysia. Its high consumption has led to global warming in which the excess heat transferred into buildings and causes discomfort to the user. For example, air-conditioning takes about 64% of energy demand in a typical office building in Malaysia due to its hot and humid climate (Kandar *et al.*, 2019). Hence, this study is essential for a better understanding of the influence of waste PET in the thermal conductivity of concrete as it is the most related parameter to define the heat transfer. Generally, low thermal conductivity tends to slow the transmission of heat in which it can contribute to the user comfortable by slower the heat transfer from the environment. In this way, user can reduce the energy consumption either by turn off or volume down the air conditioner. In this study, a low thermal conductivity concrete can be produced as PET itself has low thermal conductivity value. At the same time, this study can be promoted and confidently introduce the waste PET to the construction market as an alternative for primary material due to its benefit in thermal conductivity and same performances as normal concrete.

1.6 Concluding remarks

The structure of this chapter consists of five parts that are research background, problem statement, objectives, scope of work and research significance. This chapter generally provides an overview of the study and delivers a better understanding of how the significant consumption of PET and high demanded of concrete have impacted the environment and natural resources, respectively. This issue consequently has brought the idea of reusing recycled PET as a material in concrete production which the concept was explained in the problem statement. With the concern of global energy issue rises, thermal conductivity factor was taken into consideration to improve the performance of concrete in terms of thermal properties. Several attempts have been made to incorporate PET waste in the production of concrete, but interest however diminished and there was also limited research particular on thermal conductivity. Therefore, this study was aiming for further research concerning PET utilization in terms of physical, mechanical and thermal conductivity of concrete. Wherein, the next chapter will provide comprehensive information specifying the findings obtained from previous studies to understand the areas of concern.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reusing waste materials on the production of buildings or infrastructure materials is one of the alternatives to solve environmental problems. In recent years, many studies have been conducted to utilize waste materials in concrete (Foti, 2013). Among the waste product, polyethylene terephthalate (PET) is one of the waste materials that mainly causes environmental problems. The increase in PET bottles consumption contributes to the increasing growth of waste PET in landfills (Irwan *et al.*, 2013). Besides reducing the amount of waste disposed of in landfills, reusing waste PET can also contribute to the management of raw petrochemical products, as well as energy savings (Siddique *et al.*, 2008). Previously, Hossain *et al.*, 2016: Azhdarpour *et al.*, 2016: Khalid *et al.*, 2018 have shown the potential of using waste PET bottles in engineering applications.

On the other hand, the widespread use of concrete due to its benefits such as excellence resistance to water and most readily available material has affected the reduction of natural resources because it consists of materials like sand and gravel. It is also a necessity to enhance its properties due to its high demand. Therefore, an approach is necessary to preserve the environment while maintaining or improving the performance of concrete. This has led an investigation on the use of waste PET in

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